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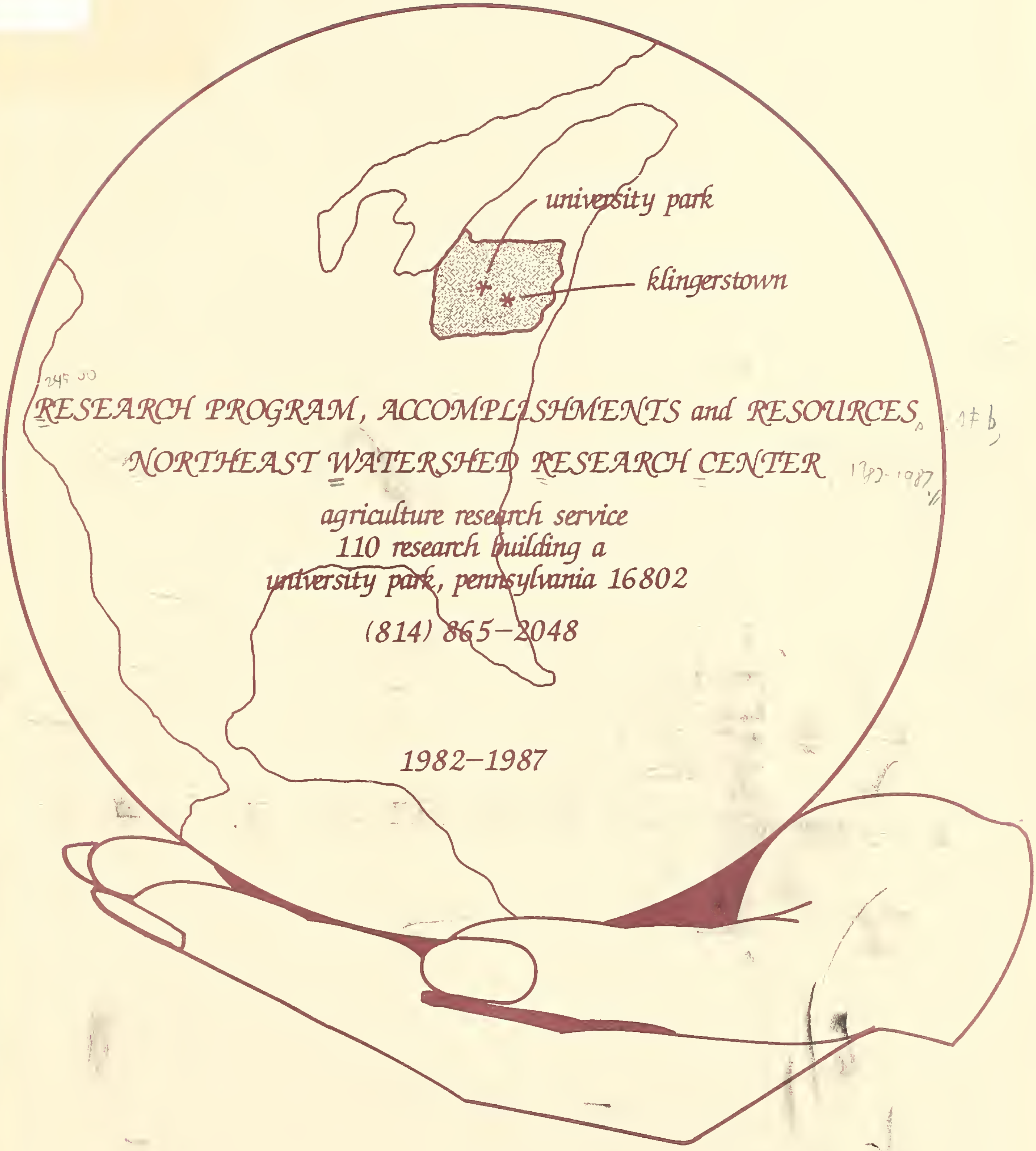

RESEARCH PROGRAM, ACCOMPLISHMENTS and RESOURCES

NORTHEAST WATERSHED RESEARCH CENTER

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RESEARCH PROGRAM

History and Description

The Northeast Watershed Research Center (NWRC) was established in 1966 as one of the last two centers to formally be added to the Agricultural Research Service's (ARS) watershed research program. This program grew from numerous small scale runoff and erosion studies, which were initiated by the Soil Conservation Service (SCS) in the 1930s and 1940s, to include structurally based flood control design and development studies in the 1950s and 1960s. During the late 1960s and 1970s, this program expanded again to include the water quality impacts of SCS's flood control agenda. NWRC's staffing and program development began during this latter period, so we developed a hydrologic research program with an emphasis on water quality. From the beginning, our program direction was largely controlled by our perception of SCS's needs and the primary hydrologic and water quality problems of the Northeast that were consistent with our mission.

Our hydrologic research program was not fixed, but followed an evolutionary pattern. Initially, our emphasis was climate, precipitation and evapotranspiration, but that soon changed to infiltration and surface runoff research. Significantly, this research was related to flood prediction at the small watershed level. This work was largely completed by 1978, and our emphasis switched to subsurface hydrologic systems. Presently, our hydrologic work is directed toward infiltration, groundwater recharge, and the interaction of groundwater discharge and streamflow. Current focus is on estimating parameters, identifying dominant processes, and modeling.

NWRC's chemical research has been directed to phosphorus (P), nitrogen (N), pesticides, and geochemicals in groundwater and surface waters. Our earliest research programs focused on P losses and transformations associated with runoff and stream transport. Later programs dealt with P transport model development, field validation, and parameter estimation. Since 1980, substantial work has been done on establishing basic N relationships within the watershed and identifying the primary N-contributing and N-consuming zones. In 1981, as part of an EPA funded project, research was initiated in erosion, sediment transport, and deposition. Since 1985, research on pesticide recharge to groundwater has been added. Our focus has been on the development of simple, accurate models and methods for estimating parameter input. NWRC's chemical data have been and are used to identify hydrologic source areas, generalized flow pathways, or zones where certain degradative chemical processes occur.

Since 1976, the NWRC, supported by special outside or in-house funds, has also addressed special problems of the Northeast. The largest project, ongoing from 1976 to 1982, involved strip mine hydrology and chemistry. Its primary objective was to identify, quantify, and model the dominant processes controlling the amount and quality of groundwater recharge in a reclaimed coal strip mine. Subsequent work (1981 to 1984) was directed toward predicting and controlling the erosion and runoff components from newly reclaimed, strip mined sites. Elements of this study are now integrated into our program. Another major project (1977 to 1982) examined the use of porous asphalt for storm

runoff detention and groundwater recharge in urban and suburban areas. Our objectives were to establish hydrologic design criteria, demonstrate their use, and define groundwater recharge mechanisms.

Our program relies heavily on the Mahantango Creek Watershed, a field research installation, which serves as an outdoor laboratory. Data that are collected on this watershed are rarely used for monitoring or surveying. Rather, hypotheses are developed and field experiments are designed using simulation techniques. Most experiments are designed to later test or field validate simulation results.

Mission

NWRC's overall mission is to identify and define 1) physical and chemical processes of hydrologic and soil systems that control water quantity and quality, and 2) degradation of water and soil resources on the watershed and source area scale. The primary area of responsibility is the northeastern United States. Our focus is on the subsurface, return flow component, which includes groundwater. Our secondary focus is on runoff, soil loss, and sediment yield. Our specific, current mission is: 1) to identify important land use water and soil resources problems of the Northeast; 2) to identify, evaluate, and quantify hydrologic, chemical, and soil loss processes critical to analysis and resolution of these problems, and 3) to formalize these results for use as planning or management tools. The Center participates in research efforts supporting the Rural Clean Water Act (RCWA), the Chesapeake Bay Program, the ARS watershed (SWAM), and field scale (CREAMS) modeling efforts.

Research Objectives

The following presents research objectives by major research units that are either ongoing or were important or productive 1982-1987.

Unit 1. Water, Chemical and Soil Losses from Northeastern Watersheds: Characterizing and Simulating Controlling Processes

Objectives: 1) Develop and test methods to simulate water and chemical transport in perched water and groundwater systems; validate these models by comparison to field data. 2) Develop and test methods to characterize and estimate space and time variations in precipitation excess, infiltration, evapotranspiration, water content of soil, percolate, and groundwater recharge. 3) Develop methods to simulate water, erosion, chemical transport, yields using distributed parameter models, develop field based methods for estimating and testing these parameters. 4) Develop and test methods to delineate critical recharge, runoff, erosion, and depositional areas on a watershed; estimate the impact of these critical areas on watershed hydrology.

Unit 2. Land Use Management Effects on Water, Chemical, and Soil Losses in the Northeast: Developing Methods of Estimation

Objectives: 1) Participate in the development of SWAM (Small WAtershed Model), particularly through chemical and subsurface return-flow models.

2) Develop user oriented methods for estimating: a) critical contributing areas, b) space and time variation in runoff, erosion, infiltration, and groundwater recharge, and c) relationship between point measurements and areal values. 3) Develop methods to estimate and facilitate groundwater recharge and percolation. 4) Develop and adapt a user oriented erosion, sediment deposition, and transport model.

Unit 3. Chemical Losses from Northeastern Watersheds: Quantifying and Simulating Chemical Processes

Objectives: 1) Delineate areas within the riparian, vadose, and groundwater zones of a watershed where denitrification occurs; assay material in these zones for rates of potential denitrification, and develop methods for estimating actual denitrification rates. 2) Improve and verify methods for estimating hydrologic parameters that describe chemical transport during unsaturated flow through soils. 3) Determine the effect of solution chemistry and flow dynamics on anion retention, and develop methods to estimate the extent to which anion retention controls solute transport through soils.

Unit 4. Water Flux and Pollution in Compacted Clay Soil: Studying Its Relationship to Field Scale Hydraulic Conductivity

Objectives: 1) Construct a field scale facility to study spatial distribution of soil water flux. 2) Install and monitor a clay layer to measure inflow, outflow, and changes in density with time. 3) Derive spatial distribution of hydraulic conductivity and evaluate the responsible factors. 4) Extend results to larger areas and determine pollution potential of leachate.

Unit 5. Water Quality in the Northeast: Evaluating Land Use Effects on Watershed Hydrology

Objectives: 1) Identify the important land use water resource problems in the Northeast. 2) Identify and evaluate those hydrologic and water quality processes and parameters critical to analysis and resolution of the problems. 3) Formalize the research results such that they are directly available for use as a planning or management tool.

Unit 6. Nitrogen Transport and Transformation in Northeastern Soils

Objectives: 1) Gather a complete N-budget data base. 2) Test the transformation, transport, and root uptake of N in available N-budget models. 3) Investigate the role of the streambank zone and sediments in adding or removing N from subsurface return flow.

Unit 7. Mined and Reclaimed Lands in Northern Appalachia: Predicting Causes and Effects of Erosion

Objectives: 1) Evaluate the Universal Soil Loss Equation (USLE) on reclaimed lands. 2) Develop improved procedures to predict energy input, surface runoff, and soil loss on mined sites. 3) Evaluate the structure and extent of variability. 4) Model erosion, and factors contributing to erosion, on mined and reclaimed areas.

Unit 8. The Relationship between Point and Area Erosion and Defining the Role of Vegetation in Erosion and Sedimentation

Objectives: 1) Model and experimentally validate scour around all vegetation. 2) Use simulation techniques to investigate parameter sensitivity in a revised Erosion Deposition Model (EDM). 3) Adapt EDM for use on microcomputers. 4) Develop a practical relationship between point and area erosion.

Unit 9. Water Quality and Quantity in Mined Areas: Determining the Impact of Strip Mining and Reclamation Processes

Objectives: 1) Identify key relationships that determine the quantity and quality of water in a mined area. 2) Generalize these relationships for application to other sites.

Unit 10. Labile Phosphorus: Estimating Its Amount and Transport at the Field and Watershed Level

Objectives: 1) Test the utility of standard, soil P fertility test data, already existent in each state, for estimating labile P. 2) Compare different P-extraction methods for estimating labile P and algae available P. 3) Test Economics Research Service (ERS) and ERS-CREAMS combination modeling approaches for routing labile P from the field to watershed scale.

ACCOMPLISHMENTS AND PROGRESS

A variety of research projects were and are operated under the major research units. Accomplishments and progress are presented by project and individually where the projects were small. To provide a complete picture of the larger projects, we have included their problem statements and approaches and referenced them to the major research units.

Ongoing and Completed Projects

1. Water Flux and Pollution in Compacted Clay Soil: Studying Its Relationship to Field Scale Hydraulic Conductivity

Scientist(s): Rogowski, A. S.
Major Unit(s): 4

Problem Statement/Approach: A major discrepancy exists between values of hydraulic conductivity measured in the laboratory and those measured in the field. This is due to 1) differences in effective cross sectional area through which water can flow and 2) short circuiting by macropores. To measure spatial distribution of soil water properties, we constructed an elevated platform and installed and instrumented a 0.3 m-thick clay layer. Following ponding, we monitored changes in density with time, infiltration, outflow, and analyzed the data using geostatistical methods. We also used tracers to study chemical transport, travel, and residence times.

Accomplishments/Progress: We used a 10 x 25m field facility to study spatial distribution of soil water flux through a compacted 0.3m clay B-horizon of a Typic Hapludult. We evaluated the spatial distributions of infiltration, outflow, and density over a period of one year. The clay layer was instrumented on a 10 x 25m grid. After ten months of ponding, steady state was attained, although rapid breakthrough of leachate in some areas suggested large pore flow. We used tracer bromide to study transport and pathways of chemicals through the layer. Breakthrough times ranged from 4 to 200 hours and recovery rates from less than 1 to 84%. We observed flow pathways and leachate breakthroughs in other than a strictly vertical direction on two-thirds of the sites tested. We analyzed the results using geostatistical methods such as structural analysis and kriging. We observed great disparity between hydraulic conductivity values, depending on the method of calculation.

We applied probability kriging to the spatially distributed flux of water in soil. The program delineated the probable location of outlier data. Assuming such outlier data distributions indicate macropores or preferential pathways, preliminary variography of experimental values can reveal whether macropores are present or not. Economy in sampling suggests taking approximately 50 field samples of inflow or outflow at random on a 1 x 1m grid, first on a test plot and then on the actual waste containment or impacted area. Subsequently, either by extending test plot scales or with the aid of additional random samples, application of conditional simulation will reproduce a number of possible scenarios over the studied area. Degree of variability associated with resultant raw variograms can give a hint about macropore distribution status and its potential for adversely impacting the groundwater at the study site.

2. Mined and Reclaimed Lands in Northern Appalachia: Predicting Causes and Effects of Erosion

Scientist(s): Rogowski, A. S. and R. M. Khanbilvardi
Major Unit(s): 7 and 8

Problem Statement/Approach: Soil loss or deposition and deficiencies in biomass productivity on mined and reclaimed areas adversely impact land use and water quality in northern Appalachian streams. Since mine soils often behave unlike natural soils, we needed to evaluate the effects of erosion, deposition, and potential for biomass productivity for each soil type. We also sought to verify USLE predictions of soil loss in the field using a rain simulator. We measured parameters pertinent to erosion and potential of warm season grasses as groundcover on reclaimed areas. Using geostatistical and conventional methods we modeled erosion, evaluated the underlying structure of variability, and identified potential soil loss producing areas on mined and reclaimed lands in northern Appalachia.

Accomplishments/Progress: We developed an erosion deposition model that was based on partial area hydrology. The model assumes the watershed to be divided into 1-acre subwatersheds. We based our prediction of soil loss on the premise that both raindrop impact and overland flow energy cause soil erosion. Depending upon the sediment transport capacity of the flow sediment may or may not move downslope.

We separated the erosion process into rill (microchannel) and interrill components. It was assumed that interrill erosion resulted from the rainfall impact and the detached sediment was transported into rills by interrill sheet flow. Rill erosion was then considered to be a result of scour in the rill and the transport capacity of the rill flow. The model generated rill sources and rill patterns, as well as extent of contributing interrill areas, determines available soil for transport at all points of a watershed.

We compared the model outputs with soil loss, measured using erosion pins. The predicted results of erosion and deposition were in good agreement with measured data. The only discrepancy was in order of magnitude: both the erosion pins and USLE overpredicted sediment yield.

We developed a biomass productivity model and used it in conjunction with a soil loss model to simulate effects of mining and erosion on the productivity potential of a 600-ha site. We computed biomass productivity, expressed as a relative productivity index (PI) ($0 \leqq PI \leqq 1$), as a product of a root distribution function and limiting, soil property levels derived from literature. We compared the effects of both scenarios. Under the assumptions of the study biomass productivity appeared more likely to decline due to mining than erosion.

The soil loss estimated by the erosion deposition model compared quite well (within 15 to 18%) to that measured by runoff sampling. We evaluated relationships between point and area erosion and the role that vegetation plays in erosion and sedimentation. We characterized spacing in an open channel flow and compared flume measurements of resistance for small cylinders (analogous to plant stalks) with results of an analytical model to interpret local scour around vegetation in the field.

We used USLE and the EDM to generate potential erosion and deposition values for a 1-year, 24-hour storm on a reclaimed site. Using a probability kriging algorithm, we transformed the data into conditional probability distributions that were presented in the form of maps of expected values, quantiles, and probabilities of values larger than a preselected tolerance level.

3. Water Quality and Quantity in the Northeast: The Impact of Strip Mining and Reclamation Processes on Water in Mined Areas

Scientist(s): Rogowski, A. S. and H. B. Pionke
Major Unit(s): 5

Problem Statement/Approach: Acid mine drainage adversely impacts water quality in many areas in northern Appalachia. Lack of knowledge about the response and behavior of newly reclaimed mine soils may limit their use. To determine key relationships that affect the quantity and quality of water in a mined area, we mathematically simulated the ongoing physical and chemical processes, then field-tested the simulations, based on field-determined parameters.

Accomplishments/Progress: Where geology is similar to that of the study area, surface mining will generally result in a mine soil with low infiltration rates (high density and low porosity). While evapotranspiration rates may be

high when water is available, hydraulic properties of mine soil may bring droughty conditions and periods of plant stress. However, hydrologic changes resulting from mining vary from site to site and will also vary over time as a result of weathering processes.

The most prominent feature of Eastern mine soils is their high degree of coarseness and high rock fragment content. Plant roots tend to concentrate along the soil coarse fragment interface. In general, the chemical constituents of the mine soils are similar to those of the natural soils, but more total bases have been leached from the natural soils due to extended weathering and significantly more extractable aluminum is found in them. The high content of carboniferous shale and coal fragments in mine soils affects organic carbon and nitrogen determinations, while comparison of their mineralogies suggests that the mine soils studied are derived from the same materials as the natural soils.

A number of mine soil properties; porosity, water retention, and particle size distribution of the mine soil layers need to be considered before deciding where and how to place acid spoils. Depth below surface and differences in particle size distributions can substantially reduce the amount of percolate or slow the amount of O_2 delivered. Analysis of both SO_4 and pyrite concentrations in spoil can identify the worst acid spoil layer for subsequent isolation and can indicate whether placement should be above or below the water table.

We found that the concentration of Cd, Cr, total soluble Fe, Hg, Mn, and Zn in spoil extracts exceeded EPA water quality drinking standards from one (Hg) to all (Mn) spoil layers. But standards for Pb and Cu were not exceeded. Generally, the trace metal concentration in the spoil extracts agreed closely with those observed in the corresponding spoil percolate while Cu and Zn concentrations in the percolate were considerably higher.

Pyrite oxidation in spoil particles, potentially the most important process, appears primarily controlled by either the pyrite oxidation or the O_2 diffusion rate. For new unweathered spoil, the experimentally determined pyrite oxidation rate compares reasonably well with published values. The rate of 0.16mg SO_4 generated/g pyrite/hour remained undiminished following approximately a 1500-hour incubation period in 20% O_2. Thus, pyrite oxidation, rather than the O_2-diffusion rates, appears to be the controlling process. As weathering removes the shallow pyrites, the O_2 diffusion or acid product diffusion rate appears to be the controlling process. When spoil particles contain substantial concentrations of acid products (3.1%) as well as pyrite (3.8%), the initial acid product losses to groundwater can be very large, even in the absence of O_2, especially where submerged or frequently flushed. As particle leaching progresses, diffusion, rather than percolation or ground water flow rates, becomes potentially controlling because of the very low diffusion coefficient of these acid products. Total acidity provides a reasonable estimate of other major chemical parameters contained in spoil drainage.

We also measured O_2, CO_2, and temperature with depth along a transect of an acid reclaimed coal strip mine over a two-year period. Spoil atmospheric

O_2 concentrations decreased with depth but approached zero only in a small portion of the transect. Most of the mine remained well oxygenated (O_2 > 10% by volume) down to 12 meters. CO_2 concentrations ranged from near atmospheric levels to greater than 15%. At some locations, especially within 2 meters of the surface, variations in O_2 and CO_2 were correlated with changes in the spoil temperature. Spoil temperature in layers below 3 meters remained in a range conducive to iron oxidizing, bacterial activity all year. Flux ratios of CO_2 and O_2 and the source/sink rates of the two gases indicate that carbonate neutralization of the acid produced by pyrite oxidation is the dominant source of CO_2.

In a second phase of the study, we developed a numerical model describing the production and removal of acid and acidic by-products from reclaimed coal strip mines.

4. Watershed Scale Characterization of Fractured Rock Aquifers

Scientist(s): Urban, J. B. and W. J. Gburek
Major Unit(s): 1

Problem Statement/Approach: Groundwater discharge forms a major component of water yield from our research watersheds. However, the aquifer source, quantity of aquifer discharge, and aquifer properties were not defined. We could not establish a complete water and chemical balance. We needed an approach to define the domain of groundwater flow, the permeability distribution in the aquifer zones, storage characteristics, and the influence of geology upon system boundaries. Our approach was: 1) to utilize well yield and water level data from within a surrounding 414 km^2 area to project into smaller study areas, 2) to develop geologic, water level, and well yield maps to define groundwater boundaries and determine the effective depth of the aquifer, and 3) to develop methods to characterize the hydraulic conductivity and water storage capabilities of the geologic materials, and 4) to provide a conceptual framework to analyze the aquifer within context of that needed for hydrologic chemical modeling.

Accomplishments/Progress: We defined the geologic section of the study area as a two layer system, both layers having low matrix hydraulic conductivity and effective porosity. The major groundwater source for wells, based on test results, appears to be from joints, faults, and tension release fractures in the rock strata. The two layers consist of a deep poorly fractured, low-permeability zone extending to about 100m in depth and a shallow (1 to 15m deep), highly fractured, weathered aquifer of higher porosity and permeability. We defined a groundwater basin for a 7.4 km^2 watershed wherein water budgeting could be completed. We found that the shallow fracture zone was continuous over the landscape, supporting a transient water table (following prolonged recharge) and a permanent water table near the watershed outlet. Future investigation of this zone is warranted because it has the potential to be a major factor in subsurface throughflow characteristics in watersheds. Because soils control water entry to this geologic zone, we are developing an *in situ* 4.3m x 2.2m x 1.1m lysimeter measurement site to measure percolate flux.

5. Geologic and Flow System Impacts on Surface and Groundwater Quality

Scientist(s): Urban, J. B.
Major Unit(s): 1, 2 and 5

Problem Statement/Approach: An approach was needed to separate the impact of land use from geochemical transformations within aquifers. The initial problem was that of identifying the location and extent of agricultural land use impact on groundwater quality. The approach was that of defining the geologic controls on subsurface water movement, determining the location and intensity of agricultural land inputs and validating the computations by analyzing water levels and chemistry in groundwater wells with subsequent measurements of stream baseflow N loading and water yield characteristics. The important factors were position of a geologic barrier, depth of aquifer, and proven superposition of topographic and groundwater divides. We constructed wells to sample waters derived only from either the deep fracture zone or the shallow fracture zone. We sampled 14 deep groundwater wells in the basin and organized the data by groundwater flow zone (recharge lateral flow and discharge). We then evaluated the data for within zone and between zone variability. We analyzed watershed hydrologic components by separating streamflows into base flow and surface runoff. We calculated water budgets and evaluated base flow vs well level relationships. We also determined nutrient budgets.

Accomplishments/Progress: We established the pattern of geologic impact using the parameters Ca, Mg, Na, HCO_3, pH, and electrical conductance. Sodium and HCO_3 increase greatly from the recharge through the groundwater discharge area. By comparing Na, Cl, and NO_3 concentrations, we observed that the decrease of NO_3 and Cl in the discharge zone appeared to be due to groundwater mixing from different zones. Thus, sources of agricultural chemical inputs could be verified by knowing which geochemical relationships were dominant and where they occurred. The geochemical results validate the proposed groundwater flow system and provide the basis for future evaluations of land use impacts on groundwater.

We developed a detailed water budget for the years 1983-1984. The total NO_3-N loss from the 7.4 km^2 watershed groundwater basin to the stream was 38,000 kg in 1983 and 29,000 kg in 1984. Groundwater flow accounted for 74% and 80% of total streamflow for 1983 and 1984. Because the NO_3 concentrations in the deep wells were about 1/3 to 1/2 of those observed in stream base flow, the shallow fractured aquifer is hypothesized to be the primary conveyer of NO_3 loading to the stream. The groundwater divide well level vs stream discharge relationship suggests that the supplying aquifer is either limited, layered, or both. This finding, combined with streamflow duration and given geologic characteristics, indicates that most groundwater flow is in the shallow fractured zone. The research basin, typical of many agricultural watersheds, has low sustainable groundwater storage, and is essentially a subsurface throughflow system rather than a classic large aquifer damped storage system.

6. Subsurface Flow and Partial Area Hydrology

Scientist(s): Gburek, W. J. and S. T. Potter
Major Unit(s): 1 and 5

Problem Statement/Approach: Partial area hydrology has been a concern for a number of years but little has been done to quantify the concept at the watershed scale or even under simple field conditions. Additionally, the interaction between subsurface flow and partial area response is now being recognized. Consequently, simulation of moisture dynamics within the groundwater discharge zone is necessary for understanding the processes controlling both storm runoff production and near stream denitrification. This project uses numerical modeling to describe subsurface flow and its interaction with precipitation and the land surface in the groundwater discharge zone.

Accomplishments/Progress: We simulated seep zone formation and groundwater discharge to the land surface for saturated flow conditions. We developed analytic models describing the extent of the seepage face for selected boundary conditions, and compared the results to those from a complete 2-dimensional saturated/unsaturated flow model. For flow geometries of relatively long shallow cross sections with mild slopes, as is typical of our watersheds, the simple analytic models predicted the extent of the seepage face to within approximately 20%.

Based on these findings, we modified a commonly used groundwater model (PLASM) to simulate the dynamics of seepage zone formation. We showed that the results from the modified model were identical to those from the analytic models, making it a useful tool for prediction of seepage zones within the irregular geometries of real world conditions. The modified model is available and a User's Manual is being developed.

We are developing a state of the art, research oriented, 2-dimensional (cross sectional) model of near stream, saturated and unsaturated flow processes, including seepage and surface runoff generation. Unique features of the model, involving intrinsic heterogeneities and grid spacing, have been verified in one-dimension, and the full 2-dimensional version is currently in the debugging verification phase. When completed, the model will be applied to field data collected by Dr. Hoover (Mahantango Watershed) and Dr. Meadows (University of South Carolina).

7. Small Scale Fracture Zone Investigations

Scientist(s): Gburek, W. J. and J. B. Urban
Major Unit(s): 1 and 2

Problem Statement/Approach: A relatively thin ([13.7m) mantle of fractured rock overlies much of the Mahantango Watershed. This layer has hydraulic properties significantly different than those of the relatively unfractured bedrock below. Delineation of the geometry and hydraulic properties of the shallow fracture layer, whose influence on the near stream zone was unknown, is critical to understanding pathways of subsurface flow and chemical transport within this typical upland watershed. This research involves field

investigations within the shallow fracture layer of two typical near stream cross sections and numerical simulations related to the findings.

Accomplishments/Progress: Rock cores to maximum depths of 30m within the sections revealed a relatively distinct fracture layer, ranging from approximately 15m deep under the stream channel to 10m deep at distance from the stream. We found that the fracture layer exhibited a seismic signature different than those of the soil and underlying less fractured rock, thus providing a tool for mapping the layer. We placed piezometers to sample hydraulic head within and beneath the fracture layer in both sections. Slug testing within individual piezometers indicated highly variable hydraulic conductivities (K) in both the fractured and unfractured layers. However, when averaged, K-values in the fracture layer are approximately 3 times those of the unfractured rock below. Measured head distributions show that lateral flow dominates in the fracture layer and converging flow patterns exist only in the immediate vicinity of the channel. The shallow fracture layer also contaminates the stream by bypassing the deeper flow system. Piezometers under pastureland exhibit almost no NO_3-N (< 1 mg/ℓ), while those under cornfields showed values that ranged from 5 to 10 mg/ℓ NO_3-N, much higher than the watershed scale discharge area values (2 to 3 mg/ℓ) reported by Pionke and Urban (1985). These concentrations are being introduced directly into the stream by the lateral flow within the fracture layer. We have developed a two-layer numerical model based on the findings of Potter and Gburek (1987) to analyze this flow system.

8. Parameter Estimation of Soil Hydraulic Properties

Scientist(s): Hoover, J. R., R. R. Schnabel, and E. B. Richie
Major Unit(s): 1 and 5

Problem Statement/Approach: Many researchers and field practitioners are recognizing that the level of detail and mathematical sophistication of numerical models has surpassed our understanding of the unsaturated soil hydraulic properties in simulated flow systems. This recognition has led to a renewed interest in refining the parametric equations that describe the hydraulic conductivity and soil water characteristic functions and in developing a better means of determining the coefficients in these equations. Our approach is to find the unsaturated soil hydraulic properties, based on unsaturated steady state flow, and evaluate the use of several closed form models that describe the soil hydraulic properties.

Accomplishments/Progress: We have developed and implemented a theoretical framework to estimate the parameters in soil hydraulic equations. We derived analytic steady state solutions, which describe a continuous unique distribution of soil hydraulic properties, while utilizing constant boundary conditions and closed form expressions for the soil hydraulic functions. We estimated the parameters by nonlinear regression of independently measured properties. We verified the procedure using synthetic soil that has parameter values virtually identical to the known soil hydraulic parameters. We designed and tested a parameter estimation cell for obtaining the steady state water and potential distributions for a sand, a silt loam, and a clay. Design changes are in progress that will enhance procedural operation, flexibility,

and accuracy. In a closely related study, we developed techniques to numerically fit the Gardner/Taylor-Luthin and Campbell equations to hydraulic conductivity matrix potential and soil water matrix potential data by a least squares procedure. The programs developed were applied to over 90 published soil/horizon data sets. Scientists can now use these closed form equations and parameters in their models to represent the soil hydraulic properties.

9. Subsurface Waters in the Soil Profile: Precipitation Excess and Flow Pathways

Scientist(s): Hoover, J. R., E. B. Richie, and R. R. Schnabel
Major Unit(s): 1 and 5

Problem Statement/Approach: Little research has been done to define the pathways of flow at the watershed scale. Most studies relate streamflow to precipitation instead of studying pathways of flow between input and output for field conditions; unsteady, unsaturated, and saturated flow in sloping layered porous media. Here, the soil zone can be most critical. Interrelated factors, such as water table depth and response to storms, degree of saturation, hydraulic conductivity, anisotropy and layering, layer slope and leakage, and convergence of flow paths near the stream, greatly influence the water and chemical flow pathways and the transport rate through soils. Our approach involved developing a particle tracking model to simulate flow rates and pathways in soils and instrumenting a typical vertical cross section in the field. We collected site characteristics and responses to modify and verify numerical models of water and chemical flow in soil.

Accomplishments/Progress: We designed a rapidly responding, bidirection reading tensiometer and incorporated it into the automated monitoring system for the cross section. We designed this innovative instrumentation system to monitor water potential continuously. The instrumentation was concentrated in soil zones where flow pathway changes were most critical, such as near the stream. Data on hydrologic response to precipitation and site irrigation have been collected for three years from the cross section. We measured water potentials during and between storms to provide an estimate of flow pathways within the field cross section. Seep zone development and dissipation and groundwater and unsaturated zone responses to storms and seasonal changes have been experimentally interrelated. These data have implications regarding the partial area concept of surface runoff that is being incorporated into the study. We have designed sensors for installation in the cross section to monitor the rapid expansion and contraction of the seep and runoff contributing zones.

We developed a particle tracking model to determine location, pathway, and arrival time of a noninteractive chemical as it migrates through a heterogeneous, anisotropic saturated/unsaturated porous media. The model is capable of accurately and relatively inexpensively simulating particle movement through a wide variety of subsurface configurations. We have tested the accuracy of the model by comparing the simulated results to analytical solutions of several subsurface flow problems. Following detailed characterization of the cross section soil parameters, we will apply the model to the cross section situation and compare the model results to field results.

10. Nitrogen Dynamics in the Riparian Zone of a Watershed

Scientist(s): Schnabel, R. R.
Major Unit(s): 3 and 6

Problem Statement/Approach: Substantial quantities of nitrogen are transported through the root zone of croplands. The fate of this nitrogen as it passes through vadose and riparian zones to enter either groundwater or surface waters has been rarely studied and is poorly understood. The proper analysis of the effects cropland-management practices on water quality requires that we determine the extent of off field processes. Our approach to this has been to quantify changes of nitrate concentration in the near stream zone, measure potential denitrification rates in this zone and within the stream channel, and develop methods to measure mass flux of nitrate through soil and nitrous oxide diffusion rates in riparian zone soils.

Accomplishments/Progress: We tested an ion exchange, resin based method for measuring the mass of inorganic nitrogen that has leached through the soil in the lab and verified it in the field. We refined and verified in the lab and field an *in situ* method for determining the diffusion coefficient of nitrous oxide in soil. Employing this method, we found the diffusion coefficient in structured soils to vary linearly with air filled porosity, contrary to many literature citations. We measured nitrate concentration in shallow groundwater and found it to decrease in the riparian zone as the stream was approached. Potential denitrification rates, measured for stream channel sediments and soil in the riparian zone, indicate that denitrification may occur within the riparian zone at least down to a soil/rock interface and may, at times, control nitrate concentration in baseflow. In a preliminary survey, we found dissolved nitrous oxide levels in many groundwater wells to be above those expected for atmospheric nitrous oxide concentrations.

11. Sulfate Retention Properties of Soil: Their Implications for Transport

Scientist(s): Schnabel, R. R. and E. B. Richie
Major Unit(s): 3

Problem Statement/Approach: Reactions of anions in soil (e.g., bicarbonate generation and sulfate retention) are thought to control the transport of applied and solubilized solutes through soil. Sulfate retention may control leaching under the conditions of low salinity and low soil pH that characterize large areas in the eastern United States. Recent efforts to mesh retention characteristics and flow dynamics have not explained observed transport phenomena. Our approach is to separate the chemical and hydrologic components and evaluate current assumptions and methodologies in each area.

Accomplishments/Progress: We found equilibrium and kinetic sulfate retention properties of a clay soil to be greatly influenced by the experimental variables employed during their determination. Solution pH and the composition of background electrolytes changed both the form and degree of sulfate retention. Projecting batch determined retention properties onto a column transport experiment resulted in poor agreement between measured and predicted sulfate breakthrough curves. The disparity resulted primarily from differential

buffering in the batch and column experiments. We developed a method to treat column effluent concentrations as averages over the collection interval rather than as concentrations at specific points during parameter estimation. We eliminated systematic errors in the analysis of kinetic data from agitated miscible displacement experiments by designing the analysis around the materials balance for the reaction vessel and a kinetic equation describing retention. We developed a numerical solution scheme to analyze kinetic data from an agitated, miscible displacement experiment that were consistent with kinetic equations and boundary conditions used in transport simulations.

12. Effects of Agricultural Land Use on Nutrient Patterns and Concentrations in Groundwater and Stream Baseflow

Scientist(s): Pionke, H. B., J. B. Urban, and R. R. Schnabel
Major Unit(s): 2, 3 and 5

Problem Statement/Approach: Groundwater quality data were collected from the 7.4 km^2 watershed periodically since 1973, but the data were insufficient and the methods nonexistent to establish land use impact patterns on the nutrient content of groundwater and to estimate the sources and amounts of NO_3 contamination. We needed knowledge and methods to define the impact of agricultural land use and N use on groundwater quality. We also needed to set up a framework for examining geohydrologic and other interactions that impact NO_3 dilution, transport, and delivery to the stream. Our approach was 1) to expand the sampling of groundwater underlying forest and cropland until a sufficient data set was established, 2) to develop N-mass balance by farm field based on manure, fertilizer, and cropping/yield records, 3) to develop a hydrologic mass balance, 4) to compare the computed and experimental results, and 5) to examine Cl as a surrogate for NO_3 in groundwater in case of denitrification.

Accomplishments/Progress: We established patterns of NO_3, Cl, and PO_4 in cropland versus forest land groundwater; the mean concentrations were 5 to 7 times higher under cropland and the distribution shifted to the higher concentrations. We established a nutrient budget for crop and forest lands and showed that P and N additions to croplands from fertilizer, manure, legumes, and precipitation substantially exceed removals by erosion, denitrification, ammonia volatility, and crop harvest. One major reason for the excess N is that little or no fertilizer-N credit was given to manure applications. Using a hydrologic budget, we converted this computed excess N to the NO_3 concentrations expected in cropland groundwaters and stream baseflow. We observed that the NO_3 concentrations agreed reasonably well with the computed values. Our computational method appeared to be reasonably accurate and showed NO_3 to behave conservatively in the watershed system beneath the soil. The relationship that we developed between NO_3 and Cl concentrations verified the conservative behavior of NO_3 at the watershed scale. However, extensive denitrification resulted in select wells within the overall watershed. We established and quantified the impact of cropland use on NO_3 concentrations in groundwater. Average annual streamflow consists of 65 to 80% groundwater and NO_3 concentrations range from several to 20 times greater

in groundwater than in surface runoff. Given that NO_3 concentrations in groundwater from cropland are 5 to 7 times higher than from forest land, the cropland groundwater link dominates NO_3 losses from this watershed.

13. Agriculturally Related Pesticide Contamination of Groundwater in Northern Appalachia

Scientist(s): Pionke, H. B., D. W. Glotfelty, and J. B. Urban
Major Unit(s): 3

Problem Statement/Approach: Agriculturally caused pesticide contamination of groundwater is a very recent issue for which little data are available for the United States or for northern Appalachia. We need to survey the problem, establish the dominant patterns and overriding relationships, and identify the impact of exceptional sites, conditions, and pesticides. Our approach was to sample springs and wells that are located on the Mahantango Creek Watershed 3 times over a 1-1/2-year cycle that included both groundwater recharge and groundwater depletion. We chose the pesticides analyses needed according to farmer use surveys for the near well areas. These were supplemented with a full set of inorganic analyses and select geologic land use, and hydrologic data. Pesticide contamination patterns were examined relative to pesticide use, land use, geology, hydrologic position, depth to water table, and the presence of other agriculturally associated chemicals.

Accomplishments/Progress: We have completed all well (20) and spring (2) samplings and have analyzed the first 2 of 3 sets of sampling. Of the nine pesticides chosen for analyses by use survey, we detected no alachlor, metolachlor, terbufos, chlorpyrifos, fonofos, or carbofuran. Atrazine contamination was widespread but at extremely low concentrations (13 to 1110 ng/ℓ). We found cyanazine and simazine only in a few wells, and at much lower concentrations. The frequency and distribution of corn production dominated the degree and spatial distribution of atrazine contamination. We observed that the highest atrazine concentrations were mostly associated with continuous corn production. Aquifer rock type and depth to water table were not important. Both Cl and NO_3 provided indices of atrazine contamination, but Cl was more reliable because of extensive denitrification in several wells. The probability of atrazine being found above the quantitative detection limit was high when Cl exceeded 3 mg/ℓ or NO_3-N exceeded mg/ℓ.

14. Characterization, Model Development, and Estimation of the Algae Available P Fractions in Soil, Suspended Sediment, and Runoff

Scientist(s): Pionke, H. B., H. Kunishi, C. Alonso, A. Wolf, and D. E. Baker
Major Unit(s): 3, 5, and Special Cooperative Agreement

Problem Statement/Approach: The accurate delineation and efficient control of the watershed source areas that contribute the most algae available P to streams requires the development of tools to make these assessments. These tools did not exist and needed to be developed. They were: 1) to develop a proper model, 2) to field test and validate the model, and 3) to develop an easy and accurate method for estimating the algae available P, labile P, and

EPC (Equilibrium Phosphorus Concentration) input data needed to make the model run. Our approach to step one was to conceptually develop, formulate, verify, program, and integrate the P-transport model into SWAM, which involved the work of two ARS units (Kunishi, Alonso) in addition to NWRC. The key component of the second step was for NWRC to develop a complete data base for a 3-year period on a small watershed within the Mahantango Creek Watershed. The third step was to form a collaborative effort between NWRC, the Agronomy Department at Penn State University, and H. Kunishi. A. Wolf and D. Baker took the lead in developing this relationship.

Accomplishments/Progress: The most complex component model, that of the labile P, was conceived, formulated, and developed by H. Kunishi. We expanded this version mathematically to include other P fractions, developed it into an operational computer model, and verified it. C. Alonso has been subsequently incorporating it into an operational version of SWAM. We collected data for 3 years from a 9-ha watershed to field test and validate the P transport model. We are presently putting these data on magnetic tape. No field testing or validation has been done. A. Wolf and D. Baker have established very good relationships between EPC, labile P, algae available P, and soil test P for the eastern and midwestern United States. Thus, the P data the model requires, the equilibrium-based soluble sediment adsorbed and algae available P, can be estimated from soil test P values. Not only is the P soil test inexpensive and in place in several states, but large numbers of historical records, identified by location, crop, soil type, and land use are also available.

NWRC's Other Significant Accomplishments

1. Porous Asphalt

We demonstrated in the field that porous asphalt is an effective surface for reducing runoff and increasing groundwater recharge. Porous asphalt designed by the USDA as a full section permeable pavement and gravel base recharged 70 to 80% of each year's precipitation without runoff. Five winters of freeze thaw did not damage the pavement. We gave the experimental plot a severe design test, applying 277mm of irrigation in 12 hours. Although this exceeded the 1000-year return interval frequency, no runoff occurred. Some seepage outflow occurred downslope but was of insignificant volume. Recharging waters are warmed as they pass through the asphalt. Winter groundwater temperatures beneath the plot are elevated by 3 to 4°C, summer temperatures by 6 to 8°C (Urban).

We developed guidelines for the design and construction of porous asphalt paving sections. We found that repeated load triaxial tests similar to those applied to conventional paving materials were suitable for evaluating the mechanical properties of porous asphalt paving materials. Although permeability of porous asphalt mixtures depends on aggregate gradation and compaction, test results for expected gradations and maximum compaction showed the pavement remained sufficiently permeable to accomplish storm water detention and groundwater recharge (Urban, Gburek).

2. Soil Conservation Service Curve Number Technique

We evaluated the SCS curve number (CN) technique using watershed data. We investigated the applicability of the CN runoff prediction technique used by SCS. We examined inherent assumptions and potential improvements using rainfall runoff data from 9 agricultural watersheds located across the United States. The Antecedent Moisture Class (AMC) II CN values, derived for each watershed from collected data, fell within the range of values determined using SCS procedures. Also, the AMC I and III CN values adequately expressed the variation observed in the watershed data. This suggests that attempting improvement of the AMC I, II, and III numbers themselves may not be justified. Runoff predicted for all storms from the AMC CN using the SCS procedure showed only a slight relationship between actual runoff and AMC class. Also, the data within each AMC class exhibited a large scatter around the average CN relation. It appears that AMC classes, as defined by SCS, are sufficiently empirical. They do not offer a physically justifiable means of adjusting CNs to account for variability in runoff due to watershed moisture conditions (Gburek, Miller).

3. Snowmelt Prediction

We developed a simple temperature range model that improves snowmelt prediction. This snowmelt model, which uses daily temperature range instead of degree days, showed an improvement in skill over the degree day model when tested on Danville, Vermont watershed data. Because temperature range data are more generally available, this development is valuable (Hendrick, Dingman).

4. Storm Runoff and Nonpoint Source Pollution

We developed a technique to define the watershed areas that contribute storm runoff directly to the channel, based on precipitation and watershed characteristics. Using design rainfalls and soil moisture probabilities as input, a map can be developed showing the return period for storm runoff for any part of the watershed and thus potential nonpoint source pollution in surface runoff to the channel system (Gburek).

5. Soil Air Entrapment and Erosion

For the first time, we demonstrated that soil air entrapment above a flow restricting zone in the soil reduced infiltration and drain flow rates in the field. We showed that shallow drainage effectively vents this entrapped soil air, thereby reducing runoff and erosion. For a 91mm storm, venting the entrapped soil air resulted in a 29% increase in drain flow rate and a 37% decrease in runoff with corresponding reduction in erosion. Tillage reduced runoff but increased erosion. As the soil reconsolidated following the tillage runoff increased and erosion decreased with time and succeeding precipitation (Hoover, Jarrett).

The mechanism of soil air entrapment and the effects of surface disturbance on infiltration, runoff, and erosion were determined in a series of related laboratory projects that were performed in cooperation with the Agricultural

Engineering Department. In soils with a flow restricting zone, the partial release of entrapped soil air through the surface uplifted a cone of soil resulting in a large volume of soil being disturbed. Erosion of the soil cone depended on air entrapment pressure and surface flow velocity. Soil air entrapment increased the erosion rate 180 and 530% and decreased the infiltration depth 45 and 55% for average and moderately high overland flow rates, respectively. For rainfall, soil detachment was highly correlated to shear strength until ponding occurred. The effect of soil splash increased exponentially until ponding depth reached 4mm (Jarrett, Hoover).

6. Interpreting Flow through Layered Soil

We developed analyses of flow through a layered soil based on Richard's Equation for one dimensional flow systems. We compared results from six different numerical models to those of the analytical model, demonstrating the value of the latter for model verification. The comparisons also resulted in a more accurate numerical interpretation of flow through soils that have abrupt changes in properties (Potter, Richie, Schnabel).

7. Effects of Acid Rain on pH of Small Streams

We used partial area hydrology and a chemical mass balance based on pH to interpret acid precipitation/storm hydrograph interactions within the Mahantango Creek Watershed. Acid rain intercepted by the stream surface and near stream wet areas temporarily reduces streamflow pH approximately one-half unit during small storms. For larger storms, which provide a greater acid load to the stream, the quality of surface runoff is controlled by precipitation quality but is buffered by a larger baseflow component. We developed techniques that allow us to quantify the immediate effects of acid rain on the pH of small well buffered streams (Gburek, Pionke).

8. K and S Parameters and Groundwater Recharge

The parameters hydraulic conductivity (K) and specific yield (S), used for design of groundwater recharge facilities, must be obtained from field based techniques that match the time and space in which the facility is expected to affect the aquifer. We compared aquifer properties that were derived from conventional laboratory and field techniques to those derived from recharge event data collected at a porous asphalt research site. Ratios of K/S, derived from a chemical tracer that was injected at the site, agree with the pumping test values. The K and S parameters that are necessary to simulate response to recharge in a numerical model of groundwater flow correspond to those derived from field oriented techniques rather than those determined from aquifer grain size or rock core permeability. Our study quantifies fractured rock parameters and indicates that the low storage coefficients observed are due to drainage from a fine fracture system (Urban, Gburek).

9. Small Watershed Model

SWAM's subsurface flow submodel has been revised to overcome earlier shortcomings and applied to groundwater data from the Mahantango Creek Watershed. We used a recharge dataset, which was derived from observed precipitation and

groundwater levels, as input to successfully simulate a two-year baseflow hydrograph record (Gburek, DeCoursey).

We have developed pesticide, N, and P models that describe chemical transport and redistribution in the channel system. They are operational and have been incorporated in SWAM. The models are based on linear adsorption isotherms (pesticides, labile P, NH_4) or mixing (NO_3). We have not considered chemical fixation or generation, except in the phosphorus model. We designed the models for the smaller well drained channel systems where travel times are relatively short; thus, biodegradation or biogeneration are not important (Pionke, Schnabel, Kunishi).

10. Sampling the Chemistry of Aquifers

We developed a method for representatively sampling the chemistry of aquifer water. The electrical conductivity, water temperature, pH, NO_3, and dissolved O_2 concentrations in pumped well water required the removal of anywhere from 0.6 to 5.3 well-bore volumes of water before stabilizing. This variability depended on the chemical parameter that was selected, the classification of the aquifer, and the hydrologic position of the well. Inflow from a non-targeted aquifer appeared to be induced by overpumping in one well. The least permeable shales generally required much greater prepumping than did the more permeable sandstones. Also, denitrification and O_2 consumption appear to be substantial in the shale zone. Because of these complexities and that no "rule of thumb" for presample pumping appears valid, we propose continuous monitoring of target parameters during pumping (Pionke, Urban).

11. Drainage Water Quality and Farm Profitability

We developed two simulation approaches to compare drainage water quality, crop productivity, and either remedial costs or farm profitability together in a decision making framework. Designed as a tool for agricultural planning and for analyzing agricultural policy alternatives at the large watershed scale, the relationship between P control costs at the farm scale and entry into a Delaware River reservoir was strongly curvilinear, and the costs prohibitive if substantial P reduction was desired. Designed as a tool for identifying farm management practices that could meet water quality constraints set at a field scale without sacrificing farm profitability, select reduced tillage, or crop rotation options for a central Pa. dairy farm were found to meet substantial erosion, N-loss, and P-loss constraints without reducing profitability (Crowder, Pionke, Ogg).

12. Hydraulic Conductivity between Nodes

We found one method of averaging internodal conductivity to be substantially superior for use in numerical transport simulations. Averaging hydraulic conductivity between nodes in a numerical simulation of solute transport significantly affected simulation results. Integrating an expression that describes the conductivity potential relationship gave results that most closely approximated the results of an analytical solution. A geometric mean of the conductivities corresponding to the moisture potentials at the nodes usually gave reasonable results, whereas the harmonic mean did not adequately simulate unsaturated flow (Schnabel).

RESOURCES

The resources of NWRC are distributed between the University Park and Klingerstown locations, which are about 145 km apart. The University Park location is on the Pennsylvania State University campus and houses the scientists, laboratories, and the scientist and support group charged with data processing, interpretation, and publication. The chemistry, soil physics, soils preparation laboratory, computer facilities and software packages, and working libraries are located there. The Klingerstown location, which is about 40 km north of Harrisburg, Pennsylvania, houses the field technicians, equipment, instrumentation, and both field and field prototype research sites. It is located within the Mahantango Creek Watershed and is near the 7.4 km^2 Mahantango Creek Research Watershed. The Klingerstown group installs, operates, and maintains field research sites; collects data, samples, and research information; critically analyzes raw data for errors or deficiencies, processes field data to prescribed formats, and transmits these data, samples, and information to University Park. There are also modest laboratory and computer facilities for onsite analyses and data processing. A map providing directions to the Klingerstown, facility is given on page 25.

PERSONNEL

Research Scientists

Harry B. Pionke received a Ph.D. in soil chemistry from the University of Wisconsin. His expertise includes chemical sediment water interaction in fluvial systems and chemical interactions in watershed systems. His current interests include identification and quantification of the chemical processes that control pesticide and NO_3 recharge to groundwater, the development of field-based isotopic or chemical methods to identify source areas of groundwater recharge, and the development of user oriented land use management based water quality models.

Andrew S. Rogowski has a Ph.D. in soil physics from Iowa State University. His expertise includes water movement in saturated and unsaturated systems, variability assessment, and erosion and deposition, biomass productivity, and geostatistics. His current interests include application of geostatistical methods to soil and water problems, evaluation of flow and transport parameters for large heterogeneous systems, and the relationship between point and area estimates.

James R. Hoover has a Ph.D. in agricultural engineering from South Dakota State University. His expertise includes soil water transport and transport modeling, and development of methodology and instrumentation for measuring soil water flow. His current interests include the development of methodology and instrumentation for measuring the storm response of seepage and runoff zones, the development and validation of particle tracking models for soil systems, and the development of parameter methods to estimate water flow in soils.

Ronald R. Schnabel received his Ph.D. in soil science from Washington State University. His areas of expertise include adsorption desorption kinetics, denitrification processes, and mathematical modeling of chemical transformation and transport. His research interests include assessing the rate and magnitude of off field processes that result in nitrogen losses from a watershed, improving and verifying methodology for estimating hydrologic parameters that describe chemical transport during unsaturated flow through soil, and developing methods to determine the anion retention controls on solute transport through soils.

William J. Gburek has a Ph.D. in civil engineering from the Pennsylvania State University. His areas of expertise include hydrologic factors affecting transport of chemical pollutants at the watershed scale and simulation of subsurface flow processes. His research interests are hydrology of the near stream environment, numerical simulation of subsurface flow, and chemical transport in fractured systems.

James B. Urban received a B.S. in geology from St. Joseph's College and has done substantial graduate work in hydrogeology at the Pennsylvania State University. His areas of expertise include well design, aquifer test design and interpretation, and geophysical characterizations using seismic equipment. His current research interests include documenting the areal scale features of shallow fractured rock, designing methods to determine aquifer parameters in fractured rock, and designing an *in situ* field lysimeter to evaluate percolate variability.

Support Scientists

Scott T. Potter received an M.S. in environmental engineering and has completed all coursework toward a Ph.D. in Civil Engineering, both at the Pennsylvania State University. His expertise is in numerical analysis of surface and subsurface flow and development of a comprehensive model of near stream hydrologic processes. He processes and interprets field data, performs computer based analyses of these data, and develops and applies numerical models of flow through porous media to watershed problems.

Donald E. Simmons has a B.S. in computer science from West Virginia University. His areas of expertise include data processing (particularly using complex and geostatistical programs), software development and adaptation, computer programming, and implementation of computer graphics. He provides system design and programming services for research projects on water flow, erosion, deposition, and biomass production, maintains program systems, and develops software to process and manage large data sets.

Secretarial

Patricia L. McClure, secretary, provides administrative and program support. She maintains office operations and supervises the technical library.

Joan E. Donley, clerk-typist, provides technical typing and administrative support.

Technicians, University Park

Charles A. Montgomery, physical science technician received his B.S. in chemistry from the Pennsylvania State University. His expertise is primarily in analytical chemistry, specifically inorganic analysis. He is skilled in using atomic absorption, gas liquid chromatograph, high performance liquid chromatography, and most common, wet chemical techniques. He provides or supervises analysis of N, P, anions, chemical tracers, trace metals, and prepares and stores samples and data.

Richard N. Weaver, hydrologic technician, provides routine programming and data analysis to NWRC. The data analyses include translation and manipulation, breakpoint reduction, tabulation, simple regression, and plotting, including x-y and contour plots. He also provides outside users with specific requested data sets.

Technicians, Klingerstown

Earl L. Jacoby, hydrologic technician, received Associate Degrees in meteorology and drafting layout and design from the University of Maryland. He is a skilled surveyor and is our most highly trained technician in the proper use, calibration, and operations of the neutron and gamma source equipment for measuring soil moisture and density. He is experienced in fabricating thermocouples and in implementing, operating, and maintaining meteorological networks, including total and net solar radiation.

Darwin B. Heath, hydrologic technician, operates the shallow cross section. He is skilled at data collection. He calibrates, installs, maintains, and operates equipment used to study soil water in saturated and unsaturated systems, including pressure transducers, soil moisture blocks, thermocouples, piezometers, irrigation systems, drainage systems, and neutron source and density probes.

Marlin L. Paul, hydrologic technician, operates, maintains, collects data from and samples the basic rainfall, surface water, and groundwater monitoring networks in the watershed. He maintains the Fisher Porter digital paper punch recording system and proofs the raw data. He also performs basic chemical analysis and sample compositing and preparation for subsequent analysis.

Clair W. Artz, drill rig operator, drills wells and cores up to 60m deep. He is a skilled electrician, plumber, metal worker, welder, carpenter, and mason.

Paul J. Dockey, hydrologic technician, assists with installation and sampling in ongoing projects. He operates the small portable drill rig and the neutron source and density probes and is skilled in carpentry, masonry, and metal work.

FACILITIES

Laboratories

The chemical laboratory at University Park is equipped with storage, preparation, and analytic facilities to perform or support mostly inorganic analyses of water, soil, and sediment samples. It is equipped with an atomic absorption spectrophotometer, high performance liquid chromatograph, and gas liquid chromatograph. Analyses for Ca, Mg, Na, K, Si, Al, NH_4, NO_3, orthophosphate, and soluble P are performed on an autoanalyzer at a contract laboratory. The chemical lab routinely analyzes SO_4, Cl, NH_4, NO_3, and HCO_3 and has the capability to analyze O_2, CO_2, and nitrous oxides. Samples are prepared here for the contract laboratory. HCO_3, pH, and electrical conductivity are determined at Klingerstown soon after sampling.

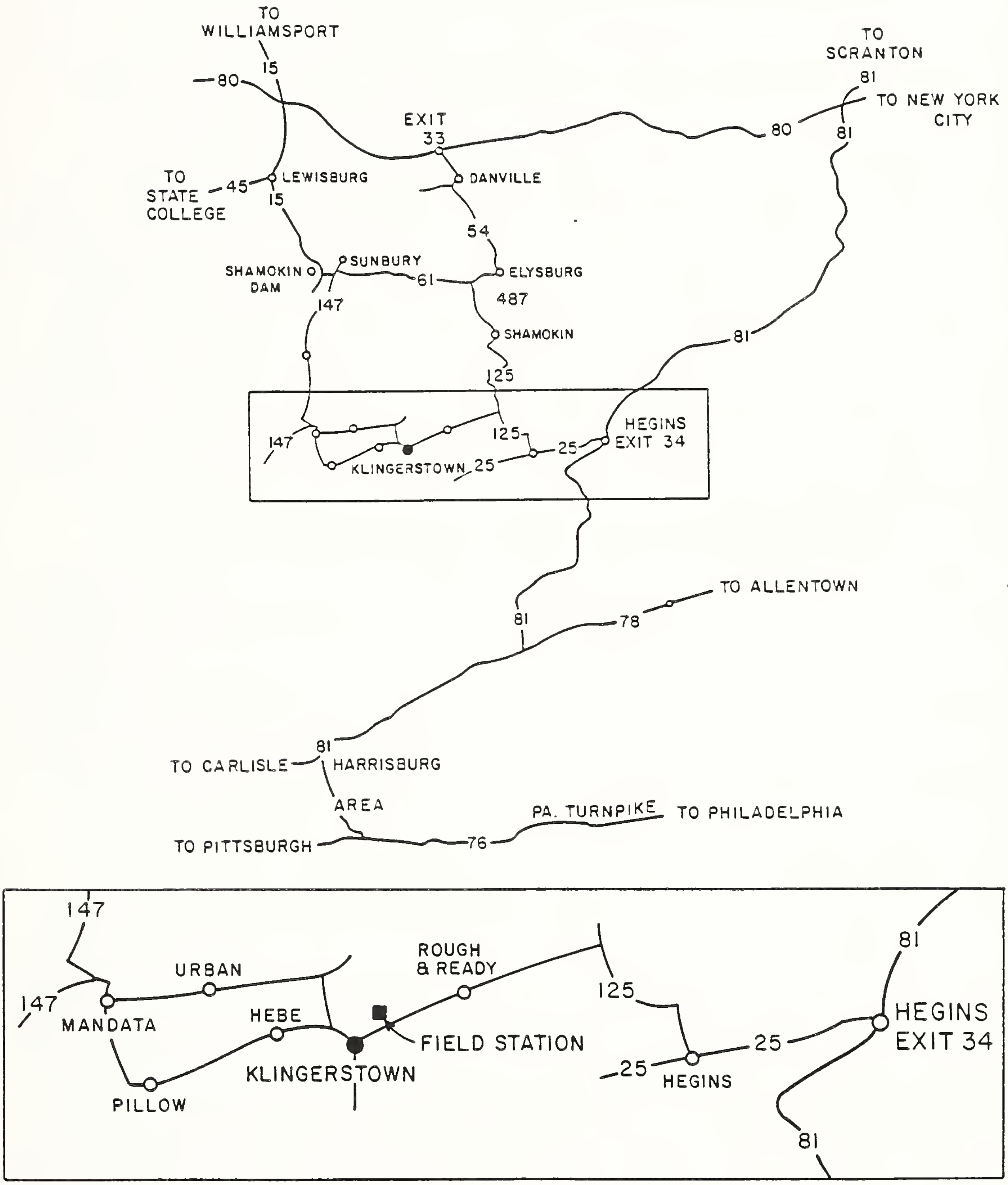
The Soil Physics Laboratory is located in the USDA Headhouse at University Park. It contains facilities for grinding, sieving, preparing soil for analysis; determining particle size distribution (sedigraph, mechanical sieving), water retention, and hydraulic conductivity of soil samples and cores; measuring mechanical properties of soil, compaction (Atterberg limit, Standard Proctor), and particle density.

Specialized Research Sites

The Research Watershed and Klingerstown facilities contain numerous research sites, but only four are listed. One is an indoor, 10 x 25m, reinforced concrete platform which is used to study the spatial distribution of soil water flux through a flooded compacted clay soil. The system is structured so that soil water content, soil density, percolation rate and chemical travel time can be measured areally on a 1 x 1m grid. The second research site is an indoor set of two large caissons, each 2.5 x 3m, that were originally used to determine and sample percolate quantity and quality in a reconstructed, coal strip mine spoil profile. Practically any combination of water and chemical sampling, continuous monitoring, or control maintenance can be established relative to infiltration, soil water redistribution, groundwater recharge, and fluctuating groundwater levels. The third site is a 2.4 x 4.6 x 1.0m lysimeter that measures and samples percolate quantity and quality responses to rainfall or irrigation in an undisturbed soil. We will install equipment for measuring and sampling soil water and chemicals, once we establish basic, overall relationships. The fourth site is a heavily instrumented slope segment that is vertically defined by instrumentation. This 3m deep instrumented cross section, which begins at the stream and continues 39.6m upslope, provides measurements of water content and water pressure with depth. It also measures water yield and the extent of seepage and runoff zones between and during storms. One major focus at this site is on interactions between groundwater seep zone, and surface runoff in the near stream zone.

Mahantango Creek Research Watershed

This data collection and research network provides meteorological, groundwater, stream flow, and surface runoff information to facilitate specific experiments as well as to provide a data base and reference point for the short term research carried out in the watershed. We collect stream flow and water quality data at the weir that drains the 7.4 km^2 watershed. We also collect suspended sediment data periodically for characteristic storms. There are a number of weirs established from past studies that drain small watersheds in cropland or forestland but most are no longer being operated. We have routinely collected continuous precipitation records and other meteorological data (humidity, max/min temperature, evaporation, accumulated windspeed). At one site, we routinely determine the chemistry of rainfall. We continuously monitor about 20 sampling and monitoring wells, installed over the watershed to different depths, in different geologic deposits and under different land uses, for water level and inorganic constituents. The hydrologic and meteorological data collection records are continuous for the last 15 years for nearly all sites mentioned. The chemical record varies from 15 years for inorganic constituents in groundwater to 3 years for the inorganics in stream flow draining the watershed. However, even where the routinely collected chemical record is relatively short term, data are often available for select past periods when specific research projects were carried out. In addition, we have carefully characterized both hydrologically and chemically the major present and discontinued research sites on this watershed.



TO WILLIAMSPORT
15
80
TO SCRANTON
81
TO NEW YORK CITY
EXIT 33
80
81
TO STATE COLLEGE
45
LEWISBURG
15
DANVILLE
54
SUNBURY
SHAMOKIN DAM
61
ELYSBURG
487
147
SHAMOKIN
81
125
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125
25
HEGINS EXIT 34
KLINGERSTOWN
25
81
78
TO ALLENTOWN
81
TO CARLISLE
HARRISBURG AREA
PA. TURNPIKE
TO PHILADELPHIA
TO PITTSBURGH
76
147
URBAN
ROUGH & READY
81
147
MANDATA
HEBE
125
HEGINS EXIT 34
FIELD STATION
25
KLINGERSTOWN
25
HEGINS
PILLOW
81

EQUIPMENT

Field Measuring and Installation

The Klingerstown unit is equipped with a woodworking and specialty metal-fabrication workshop and two drill rigs, including a truck mounted rig for well installation down to 60m. Portable equipment for measuring select geologic, hydrologic, and chemical properties or parameters is available. The geologic equipment includes seismographs, an earth resistivity unit, an electro magnetic induction unit, a laser beam optocater unit, and a hydraulic packer for testing wells. The hydrologic equipment includes devices for measuring flow rate, water level, infiltration, and soil water measuring devices such as surface, depth, and depth density probes. The chemical equipment includes pH, electrical conductivity, redox, and dissolved oxygen probes. Individual research sites are equipped to sequentially monitor and sample. The equipment includes weighing recording raingages, water level recorders, hygrothermographs, evaporation pans, max/min thermometers, anemometers, water pressure recorders, and automatic pumping samplers. Most of these recording instruments provide paper punch tapes which are translated later to magnetic tape. The rest are recorded directly on magnetic tape cassettes or on charts. We also have a rainfall simulator with two semi-tanks and a tractor.

Computer

Nearly all computer services are purchased from the Pennsylvania State University Computer Center which provides access to an IBM 3096-200 OS/XA and accessories such as laser printers. Our access is through 9 HDS terminals on dedicated lines that can be operated on an interactive (9600BAUD) or batch mode (2400BAUD). One terminal is connected to a plotter. The in-house capabilities are minimal; we are using a Wang 2200C to read and process data from cassette tapes generated from research installations at the watershed and to provide hardcopy from the Penn State System on an in-house printer. At Klingerstown, we use an Apple IIe with printer/plotter to process data collected from the hydraulic conductivity study.

UNIVERSITY AFFILIATIONS

NWRC is affiliated with several Penn State University Departments, has supported graduate students, and has joined with Penn State faculty in proposing and doing research. Five of our six research scientists have adjunct professorships and are members of the graduate faculty. Student supported work has been funded in part by EPA or SCS monies passed through to NWRC to accomplish specific tasks. For each student a NWRC research scientist has served as thesis advisor or major professor. During the last 5-year period several joint Penn State University-NWRC projects were formally proposed through the Agricultural Engineering Department and two were funded by the Office of Water Resources Technology. Using ARS funding and their own resources NWRC and the Agronomy Department initiated and have completed a relatively large and complex study of labile P. Most of our research scientists generally are members of several university committees and serve on graduate student examination

committees. Our scientists have general access to library facilities and, to some degree, other research support available to Penn State faculty. NWRC has a Research Support Agreement, leases and contracts with the University through which it procures office space, computer services, laboratory analysis, and student help.

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